Environmental Monitors on Lobster Traps
Phase IV: Drifters

Final Report to Northeast Consortium

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Abstract

A variety of questions have recently arisen concerning the role of the coastal currents in transporting particles along the western boundary of the Gulf of Maine. The mechanisms that advect, for example, lobster larvae in the near-surface layer are now under investigation. How are these planktonic particles dispersed and delivered along the entire coast of New England. What regulates the apparent temporal and geographic variability?

With cooperative research funding from the Northeast Consortium, 82 drifters were built (17 of them with GPS transmitters) by Southern Maine Community College marine science students and deployed by the New England lobstermen. These drifters were deployed at several locations ranging from the Canadian border to Massachusetts Bay during the late spring-summer 2004 to study the advective pathways of lobster larvae. Concurrently with this eMOLT project and in the following year, 61 more satellite-tracked drifters were funded by other sources and built by SMCC to examine, for example, harmful algal bloom transport along the coast.

Given more than 50,000 kilometers collectively logged thus far, statistics such as residence times, mean velocities, and preferred pathways are compiled for various areas of the coast. Lagrangian flow is compared to Eulerian estimates from near-by moorings. Numerical simulations ranging from simple Ekman theory to sophisticated 3-D ocean circulation models are being tested.

Results indicate that the Maine Coastal Current is a strong and persistent feature throughout the summer but that particles can a) deviate from the seasonal mean core fairly regularly and are often reentrained, b) follow a slower (10 cm/s), less constrained path in the western portion relative to the eastern (13 cm/s) section, and c) be easily affected by both minor wind events and small scale oceanographic structure. Travel times along the entire western side of the Gulf of Maine are typically less than two months.

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Introduction

A variety of investigations have been made on selected sections of the Maine Coastal Current in the last decade. Much of the focus has been on the Mid-coast region in the vicinity south of Penobscot Bay. Both the Ecosytems Response to Harmful Algal Bloom (ECOHAB) and the Marine Ecosystems Response to Harmful Algal Blooms (MERHAB) projects have examined the processes associated delivering particles towards the Casco Bay and intervening estuaries. The effects of river plumes, upwelling/downwelling, and upstream source waters have been considered. The bi-furcation of flow off a couple different locations such as Schoodic and Penobscot is often a topic of discussion (Pettigrew et al, 2005). How often does the Eastern MCC, for example, flow near-shore in the southwestern section of the coast? Both the Mass Bays Project (Geyer et al,1992) evaluation of the Boston sewage disposal site in the early 90's, the more recent studies on the HAB event in 2005 (Anderson et al, 2005), and right whale prey advection in the Great South Channel have examined similar questions pertaining to the pathways of flow at the more-southern end of the region. This project (Environmental Monitors on Lobster Traps) looked at the advection of coastal current along the entire Western GoM during the summer of 2004.

Several modeling studies have attempted to simulate the many time and space scales associated with the Maine Coastal Current in the past few decades. Beginning with Brooks et al (1994) investigating the spring time flow patterns in the EMCC, subsequent studies by Lynch et al (1997) and Xue et al (2000) examine the seasonal flow fields. More focused studies of river effects (Fong et al, 1997; Geyer et al, 2004), assimilation of seasurface elevation (He et al, 2005; Bogden et al, 1996), and advection of lobster larvae (Incze and Naimie, 2000) provide detailed description of specific processes. The primary objective of the drifter deployments discussed in this report is not necessarily to resolve all the complexities of the flow field but rather to help validate these numerical simulations and hindcasts.

The primary objective of this report is to provide a detailed review the observations taken as part of the eMOLT project 2004. The summary of the compiled drifter archive is left for future publications. While the goal of future publications will be to compare and contrast the flow field at the various regions along the coast and in different years, this report provides particular results from the 2004 eMOLT project segment including individual drifter tracks.

It is important to note that there are three other phases of the eMOLT project, documented elsewhere in final reports. These include our efforts to maintain temperature and salinity probes on traps (Phase I and II, respectively) and the database management process that this entails (Phase III).

According to NEC final report standards, we begin now with our “Project Objectives” followed by a list of participants and a description of both the methods and the data. The bulk of the report comes under the heading of “Results and Conclusions” followed by several other aspects of the project near the end of the document such as “Partnerships” and “Impacts and Applications”.

Project Objectives and Scientific Hypotheses

In order to understand the inter-annual variability of lobster stock recruitment processes, it is necessary to both monitor and model the underlying physical environment. Are there large changes in the conditions and pathways of drift during critical stages of larval development? The three most-important variables in describing the physical oceanography of the Gulf of Maine are temperature, salinity, and current velocity. Having setup an infrastructure for measurement and management of the first two data streams (temperature and salinity) in earlier phases of eMOLT, the objective of this study was to obtain observations of the third (current velocity). While each of these variables is dependent on the other, all three are required in a complete description of the physical system. As in the case of atmospheric weather models, in order to generate realistic output for the entire three-dimensional field, it is necessary to repeatedly assimilate data at key locations throughout the geographic domain.

Lobster catch off the coast of northern New England has reached historically high levels in recent years. If and when it begins to fall in the near future questions will undoubtedly arise on the role of the environment and long term climatic changes. The discussion is already underway, in fact, along the Southern New England coast. The absolute causes of lobsters demise in that area is still under debate (Allen, 2003). Of particular concern is the potential effect of long-term climatic change. How will the lobster population respond to an apparent warming of the environment over a long time scale? Given a confounding influx of cold ice melt from the north, it is possible that this large scale weather pattern is affecting the northern New England region less so than the southern. If so, what are the transport mechanisms providing this Canadian source water to the Gulf of Maine and how quickly do particles move along the coast? The North Atlantic Oscillation complicates this long term trend as it occasionally provides relatively warmer water masses to the Gulf of Maine and can thereby alter not only the temperature and salinity throughout the region (at depth in particular) but the circulation pattern as well. These large scale, long-term questions can only be answered by Gulf-wide, multi-year, low-cost, collaborative studies with the help of fishermen.[1]

What is the long-term future of our coastal waterways? Since there will undoubtedly be more calls for offshore industrial structures such as wind towers and underwater tidal current generators, we need to assess the environmental impacts and feasibility of each proposal in specific areas of the coastal zone. Do we have enough understanding of the residual currents in each location and the degree of variability expected in those locations? Studies of this type need years of data to develop a statistical understanding of various dynamics. A long term (multi-year) monitoring strategy as we are testing with this experiment may provide a low-cost solution.

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[1] These first few paragraphs are taken near-verbatum from the original proposal.

Motivation

The motivation behind the eMOLT drifter project resulted from a set of pilot experiments that began before the NEC proposal was written. Four GPS/ARGOS drifters were deployed off the R/V WEATHERBIRD off the mouth of the Penobscot in the Summer of 2002 (Figure 1). The results were limited due to the fact that all units either washed ashore or were picked up by curious lobstermen within a few days of deployment. In the spring of 2003, a dozen electronic-less drifters were built by SMCC students that year and subsequently deployed off the R/V OCEANUS along with several GPS/ARGOS units. These deployments were funded in part by NH Sea Grant (Dr. Lew Incze) and the Marine Emergency Response to Harmful Algal Blooms (Dr. McGillicuddy), respectively. The results of the 2003 preliminary study are presented in Figure 2 and 3 below. While the GPS/ARGOS drifters (leftover from previous funded projects) provided far more detailed information (Figure 3), each of the dozen electronic-less drifters deployed that year (Figure 2) was subsequently sighted and reported by mariners and provided similar statistics on the portion of units drifting ashore (~25%) relative to those advecting towards Georges Bank (~75%). This preliminary result lead to the idea of a more extensive set of deployments proposed for 2004. Could we develop more cost-effective instrumentation to answer certain research questions concerning the ultimate fate of planktonic particles in the Maine Coastal Current?

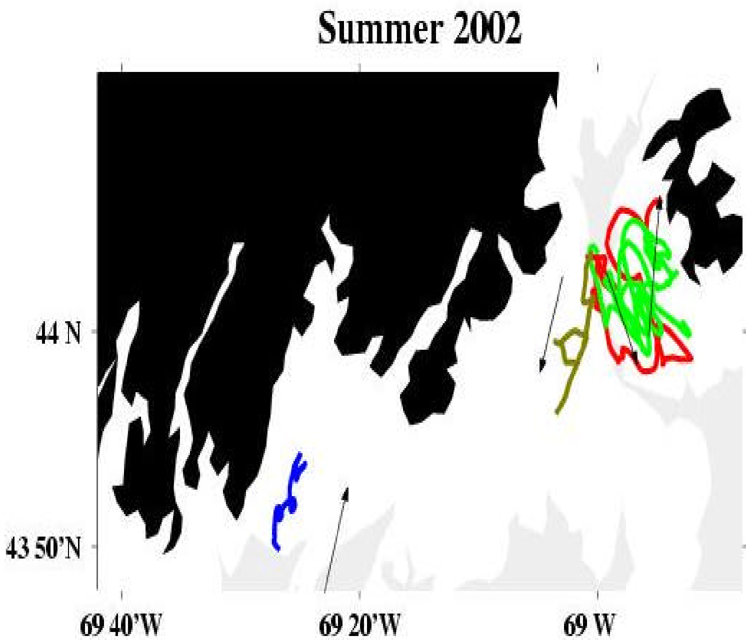

Figure 1. Seagrant-funded drifter deployment at the mouth of Penobscot Bay in July-August 2002 that partially motivated the eMOLT study in 2004. The arrows represent the general direction of flow for the four color-coded drifters. That deployed west of Monhegan, for example, headed north towards Muscungus Bay.

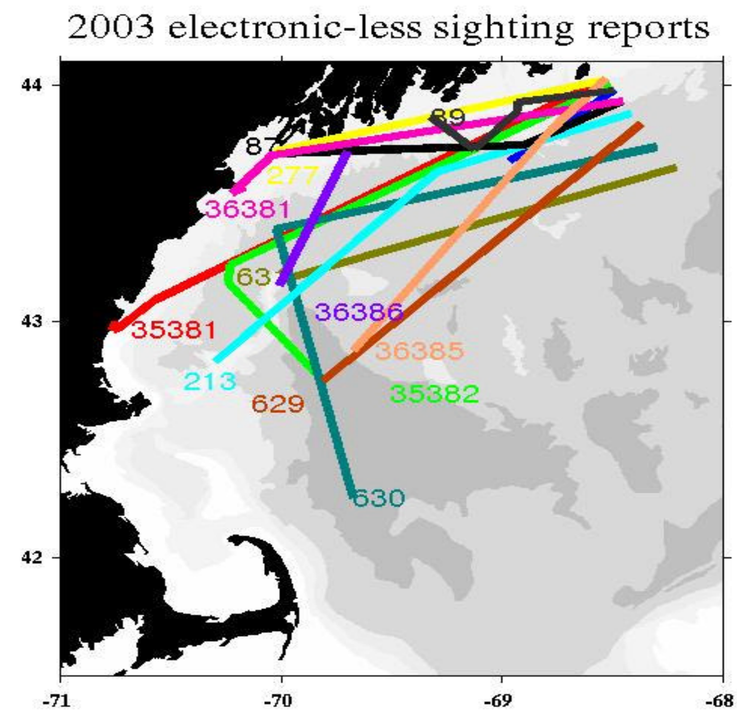

Figure 3. Seagrant-funded electronicless drifters deployed in 2003 as a pilot study to the eMOLT deployments in 2004.

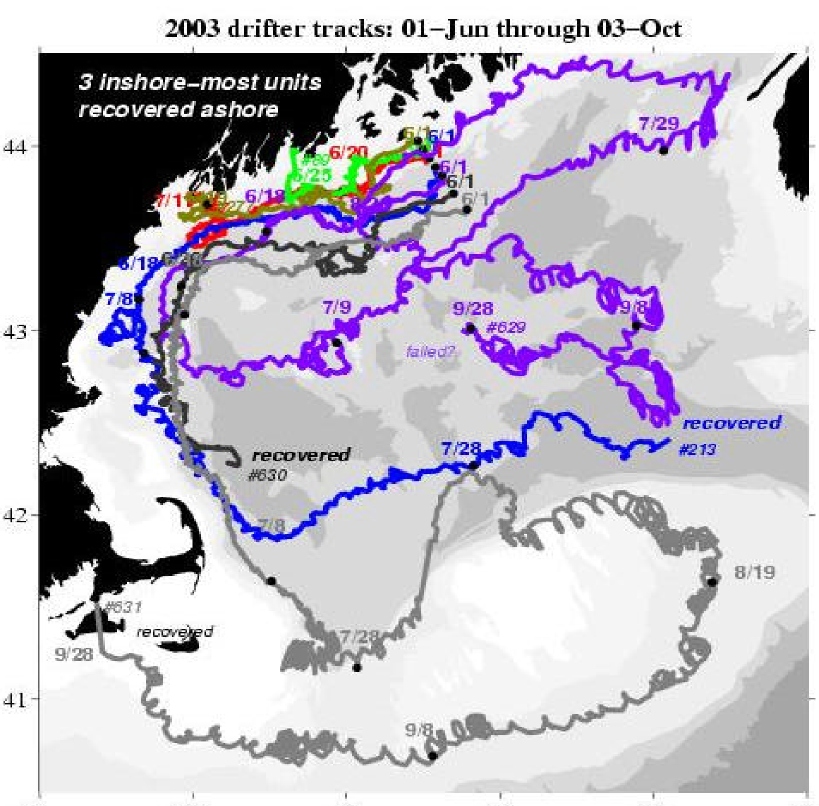

Figure 2. The MERHAB-funded drifter deployments in 2003 that further motivated the eMOLT study in 2004. Several GPS/ARGOS drifters were deployed off the Isle au Haut and three washed ashore.

Participants

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While the primary administrators are listed above, many other people were involved with the project. The lobstermen involved with drifter deployments are listed in Appendix I. SMCC faculty & students involved with eMOLT drifter production are listed in Appendix II. Mariners and beach-combers that reported drifter sightings are listed in Appendix III. All are acknowledged for their efforts.

Methods

Drifter design & construction

The drifters built for the 2004 eMOLT project were a standard oceanographic configuration as originally designed for the Coastal Ocean Dynamics Experiment (Davis, 1985). They consist of four 19"-wide by 36"-tall, subsurface, cloth sails mounted orthogonally around a 4-foot length of 2-inch PVC pipe, supported by 1cm-diameter fiberglass rods, floated by 4 pairs of fish net buoys, and ballasted by a 7 pound window sash weight (Figure 4). The flotation was tethered to the 55" fiberglass rods with a length of bungy such that the sails were properly submerged below surface. The ballasting ensured that at least half the floatation was also submerged according to WOCE specifications (Sybrandy et al. 2003) Flotation was secured with a series of stainless washers and cotter pins. These are designed to follow the upper meter of the water column with minimized wind drag. A complete description of the design (including an extensive gallery of photos) is posted on the emolt.org website under "Drifter Manual: design, construction, and use".

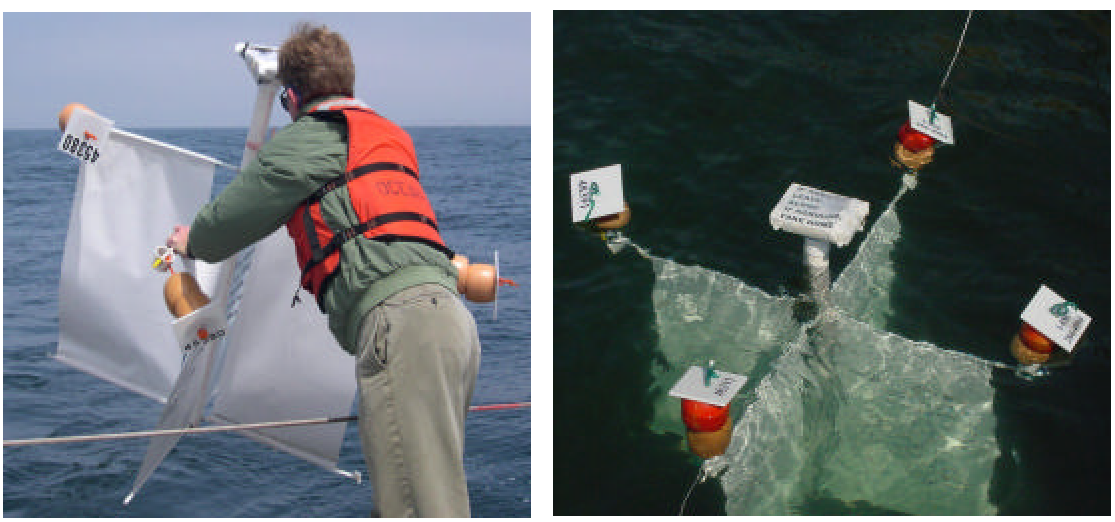


Figure 4. Dennis McGillicuddy deploying an eMOLT surface drifter (left panel). As seen near his left hand, the flotation tether swivels on the fiberglass rods with a 2" length of 2" PVC pipe fixture. As seen in the right panel, the unit in the water has very little windage.

Approximately one quarter of releases made in 2004 were fitted with experimental, low-cost, GPS transmitters, the same technology used for tracking vehicles on highways. These essentially expendable units performed well, generally surviving about two-months at sea in 2004 in order to provide sufficient time to track water parcels along nearly the entire length of the Western the Gulf of Maine. Their survival rate fell off in oceanic conditions as encountered, for example, on Georges Bank. We suspect some loss of instruments due to the bungy-tether fatigue/stress resulting from weeks of constant wave oscillations. The bungy tether was replaced by stainless wire and, in some cases, ¼-inch nylon cord in 2005.

The electronic-less majority of the 2004 drifters were fitted with a ¼ inch fiberglass rod supporting a small (12cm) brightly colored flag extended 2 meters above the seasurface to provide increased visibility. Nearly half of these flags, however, failed to survive the deployments having apparently been destroyed by the wind and waves. These units were well marked with a toll free phone number in a variety of places on both the flotation and the sails. All four sails had information concerning the study including the instructions on reporting the sighting, the institutions involved in the study, and information on where it was deployed, by whom, and why. An automated phone system was set up (piggybacked on an existing NMFS mandatory dealer reporting system) to prompt mariners for the drifters id number along with a position in either lat/lon or time delays. A lot of effort went into notifying mariners in the months proceeding the deployment about the system including a set of brochures, newsletter articles, notices to mariners, and talks at meetings.

Figure 5. Proctor Wells holding the surface configuration of a drogued drifter with Monhegan Island in the background.

Data entered via this phone system arrived directly in an ORACLE database at the Gloucester lab and was immediately accessible for processing at the Woods Hole lab. In hindsight however, the automated phone system was hardly necessary since the number of reported sightings could have been easily handled by direct phone calls to humans. As noted in the discussion below, the electronic-less units cost less than a quarter that of the GPS units but the GPS units out-performed the electronic-less units by nearly 10-to-1 in terms of kilometers-tracked-per-$-spent.

In the following year, with additional funding from NEC and the Woods Hole Center for Oceans and Human Health (WHCOHH), a drogued drifter was developed to monitor currents below the surface. The students at SMCC worked during the winter and spring of 2005 to design and build a 9-meter long holey sock drogue as picture in Figure 6. After some experimentation in Casco Bay with prototype units, they successfully devised a unit with 90cm-diameter fiberglass hoops every 3-meters supporting a sturdy vinyl cloth material with two 30cm holes cut (as shown) between each hoop section (again according to standard WOCE specification). The sections of cloth and hoops were secured with durable HC33 glue that proved to hold up to the marine environment. Problems with

Figure 6. Holey sock drogue designed and built by SMCC students with Casco Bay in the background.

hoops and ballast secured with small tie-wraps were corrected in later deployments. Experiments were conducted to determine proper amounts of ballast for keeping the drogue vertical in the water column. While the exact quantity was difficult to determine given the different oceanic conditions that the rig was expected to experience, a total range of 15-20 lbs of commercially available diver's weights were secure in three locations on the bottom-most hoop. The drogue was connected to the surface electronics with a stainless steel 3-point bridle and 10 meter long tether. The surface unit consisted of a 2-foot length of 2” PVC pipe below a 2'-length of 4” PVC pipe. The upper 4” pipe housed the electronics (Figure 5). The coupling between the two pipes was bored-out in order to slip the 2” pipe up into the housing and be capped. The flotation consisted of a combination of hose-clamped net buoys and a set of customized foam collars that were specially made for us by Gilman Corporation in Gilman, Ct. While the collars provided a cleaner and professional look, it was subsequently decided they were not worth the cost. The biggest trouble with the new drogued drifter design was the coupling connection between the two PVC sections. The water-tightness of this fitting was questionable in a few of the prototype units but modifications thereafter resulted in some of these units surviving weeks of rough seas.

Another additional feature added to the design in the Summer of 2005 was a telemetered temperature sensor that fed into the cap of the housing unit with a compression fitting. This feature successfully provided telemetered seasurface temperatures off the dock in Woods Hole but completely failed in its first deployments in rough waters off mid-coast Maine. The telemetered temperature feature was therefore eliminated in subsequent units deployed by Lew Incze off mid-coast Maine in July 2005.

Drifter data processing and analysis methods

The hourly GPS fixes were available within minutes from the passage of the low-orbiting GLOBALSTAR satellite and posted on the web. A series of near-daily processing steps were subsequently taken to plot, analyze, and post the data on the www.emolt.org “drifter study” page under “Observations thus far”. All data was stored in an ORACLE database in Woods Hole. Animations and GIS overlays were generated subsequent to each set of deployments (including illustrations of observed wind vectors) and posted on the web as well. Summary plots were posted by time and by location. A web mapping utility was built which allows users to build customized maps of selected drifter tracks with a variety of basemaps.

While it is essentially impossible to properly detide the Lagrangian tracks, drifter velocities were calculated given the near-hourly fixes and “residual” flows were derived by low-pass filtering the series.

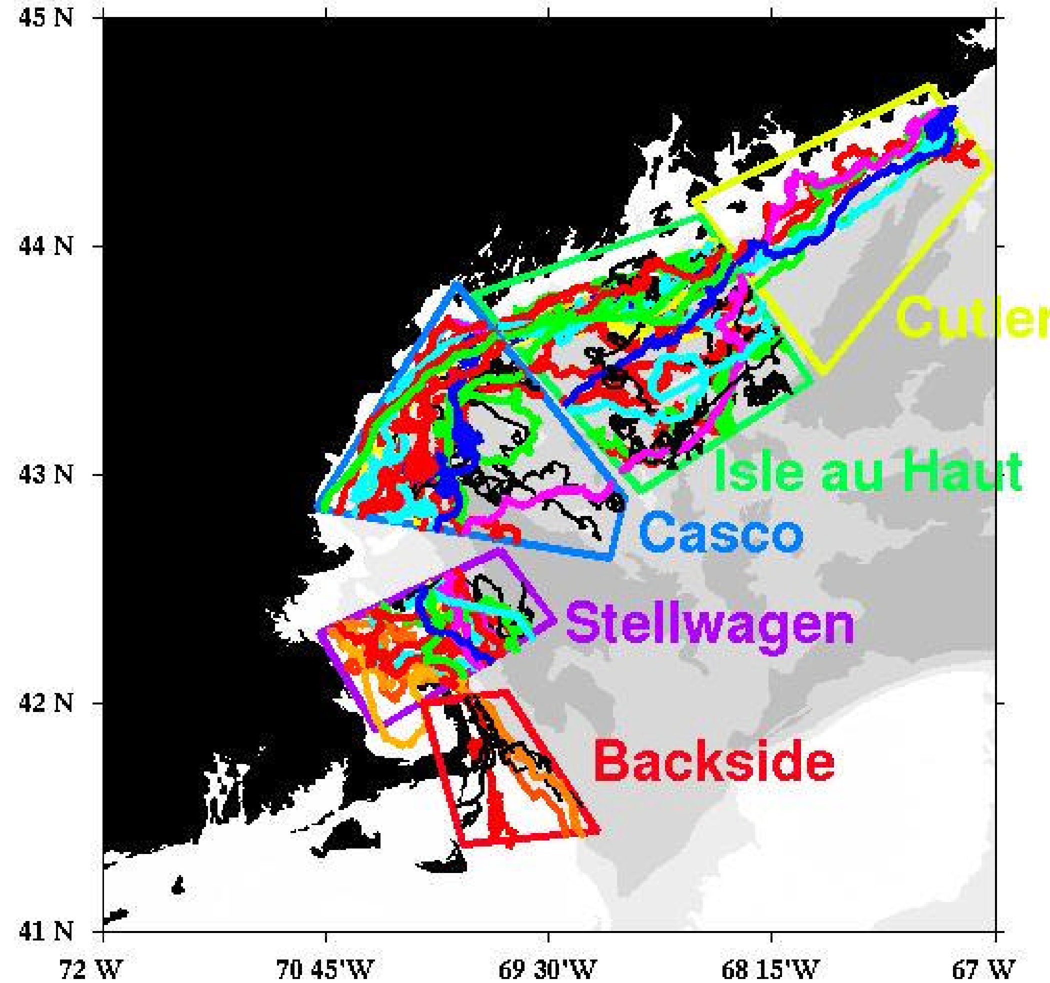


Figure 7. Illustration of how the coast was divided up into sections for purposes of computing regional statistics.

In order to document the characteristics of flow off particular sections of coastline, the Maine Coastal Current was arbitrarily segmented into five regions (Figure 7). Statistics such as mean velocity and transit times (along with multiple measures of variability) were calculated for each region. While "transit times" pertained to units that traversed the entire box, statistics were kept on "percentage loss" to both the inshore and offshore sides of each box. The objective in this last calculation was to estimate the degree of exchange between the coastal current and the estuaries and mid-gulf, respectively.

Another characteristic of interest is the dispersive nature of the flow in each box. Using a slightly modified method of estimation (to filter effects due to the tides), "integral lagrangian time scales" are calculated for each unit. Since the generally accepted procedure in the literature pertains to large scale oceanic flows where the M2 tide is generally not a factor, a new method is proposed here to use local maximums in the autocorrelation of the velocity series. The rate at which these local maximums, one per M2 tidal cycle, decrease in time depends on the lower frequency processes (wind, offshore pressures). This provides an approximate measure of the period it takes for a drifters residual velocity series to become decorrelated or, as noted by other investigators in the literature, "the number of days it takes for a drifter to lose its memory".

Relative to other coastal shelf regions around the country, the Western Gulf of Maine is fairly well instrumented with Eulerian current measurements. Given several moorings and a few CODAR installations installed and well maintained by the Gulf of Maine Ocean Observing System, comparisons can be conducted with our Lagrangian observations (Figure 8).

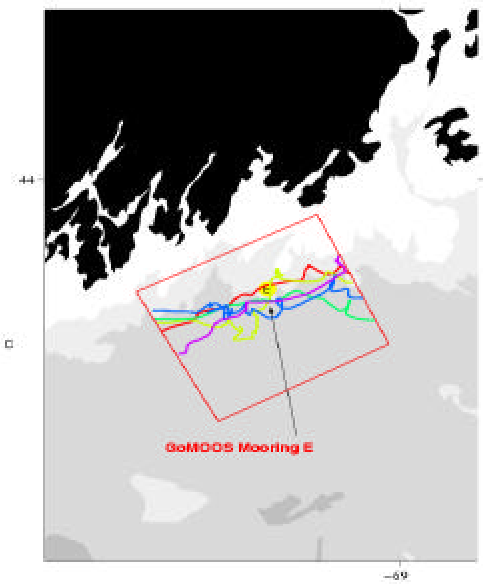


Figure 8. Illustration of how fixed mooring (Eulerian) statistics are compared to moving (Lagrangian) drifter statistics.

As in any observational study of this nature, an analysis of events often helps describe the nature of the flow better than pure statistics. A number of individual drifter tracks can be singled out and associated with particular processes. Some of them, for example, are shown to be a) retained in certain zones for lengthy periods, b) tracked in and out of an estuary systems, c) reacting to small scale density structures as observed by satellite SST imagery, and, of course, d) reacting to episodes of wind-driven upwelling and downwelling.

Finally, it is instructive to test a few models against the observed drifter tracks. As a preliminary experiment, a simple Ekman model was developed where the only forcing was the nearby wind observations. Given a residual flow prescribed by calculating the overall flow velocity from start to end of the track, the Ekman component of flow is tested to explain the variability from a straight-line trajectory. How much of the floats meandering can be ascribed to the wind forcing?

Data

As originally proposed, drifters were deployed by lobstermen in the first few days of each month (June through September) along four different transects and at four different water depths per transect (Figure 9). The exception was the transect off of the Isle Au Haut where five units were deployed each month (to be consistent with a transect deployed the previous year of 2003). Hence, 17 drifters were deployed each month at the same sites (Table 1) with some effort made to deploy them at the same phase of tide experienced in the first June deployment. Lobstermen were instructed to deploy within a few days of the first of the month to allow them to both capture the correct phase of tide and account for weather.

The original intent was to choose sites in multiple water depths generally ranging from 40 to 100 meters in hopes of documenting the isobaths associated with the inner band of the Maine Coastal Current. Actual depths of each transect varied, however, depending on the local bathymetry of the transect. Those off Cutler and Cape Small, for example, were deployed in shallow depths to insure they were contained in the coastal current. In most cases, the cross-shelf topography does not consistently deepen in the offshore direction. One of the primary objectives was to determine at what depth particles tend to be advected shoreward vs continued transport towards Georges Bank.

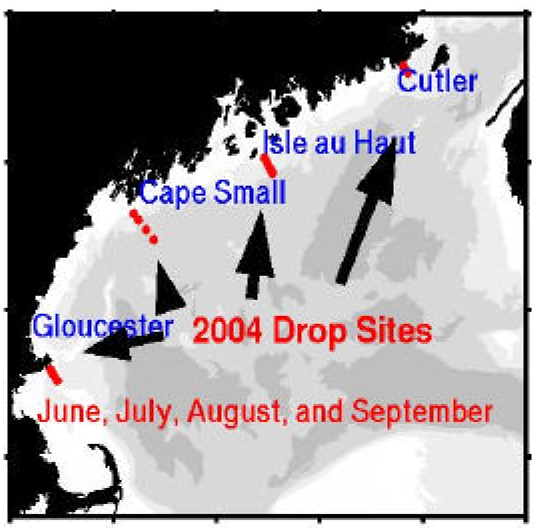


Figure 9. Locations of drifter dropsites in 2004 eMOLT project.

The actual transect was chosen along a particular loran line (to make it easier for the lobsterman) that was most perpendicular to the coast. Transects were spaced along the coast such that at least some units would likely transit from one to the next in a few weeks time. The Cutler section was chosen to document the Eastern Maine Coastal Current. The remaining sections were chosen to document the portion of flow (if any) that is advected into Penobscot, Casco, and Mass Bays, respectively. Dropsites and lobstermen involved are listed in Table 1.

Table 1. Dropsites for eMOLT drifters in 2004. (Note: The 2nd digit of the ID number increased with each month. June involved the 46000 series while July involved the 47000 series, for example.)

Locations	ID (June)	Deployer	Depth (m)	Lat (dd)	Lon (dd)	TD1	TD2
Gloucester	46201	Sooky Sawyer	34	42.6	-70.61	13810	44330
Gloucester	46202*	Sooky Sawyer	52	42.57	-70.59	13810	44320
Gloucester	46203	Sooky Sawyer	52	42.55	-70.57	13810	44310
Gloucester	46204	Sooky Sawyer	66	42.52	-70.55	13810	44300
Cape Small	46391	Ed Hunt	9	43.65	-69.8	13130	44540
Cape Small	46392*	Ed Hunt	17	43.61	-69.76	13130	44525
Cape Small	46393	Ed Hunt	25	43.54	-69.68	13130	44500
Cape Small	46394	Ed Hunt	50	43.47	-69.61	13130	44475
Isle Au Haut	46381	Stevie Robbins III	64	44.03	-68.54	12546	25778
Isle Au Haut	46382*	Stevie Robbins III	70	44.01	-68.51	12549	25767
Isle Au Haut	46383	Stevie Robbins III	57	43.98	-68.5	12553	25757
Isle Au Haut	46384	Stevie Robbins III	76	43.96	-68.48	12557	25747
Isle Au Haut	46385	Stevie Robbins III	90	43.93	-68.45	12562	25736
Cutler	46471	J Cates & N Lemieux	10	44.65	-67.19	11930	25750
Cutler	46472*	J Cates & N Lemieux	40	44.63	-67.17	11934	25745
Cutler	46473	J Cates & N Lemieux	40	44.62	-67.16	11938	25740
Cutler	46474	J Cates & N Lemieux	46	44.6	-67.15	11942	25735

- units with GPS transmitters

A drifter-ID naming convention was devised to allow downstream mariners to determine the origin of the unit. The five digit code refers to the year, month, latitude, longitude, and its position in the offshore direction where, in the case of latitude and longitude, the second digit is used. Drifter ID 48381, for example, refers to the drifter deployed in August 2004 at approximately 43N & 68W and is the first one deployed heading offshore. This same ID convention was used for nearly 59 other drifters deployed independently of the eMOLT batch in the Gulf of Maine in the last few years so that users may query the ORACLE database according to ID.

In an effort to compile the all the drifter data available for the Western Gulf of Maine (including all tracks collected before, during, and after the eMOLT drifter project), datasets were obtained from individual Woods Hole Oceanographic Institute investigators and loaded into the same ORACLE table. A listing of these sets is provided in Table 2 to document the current collection as it exists at the time of this writing. The graphical illustration of this archive is presented in Figure 10. The datasets listed in the table are now served via OPeNDAP/DODS from the emolt.org “Data Access” site.

Table 2. Additional drifter data compiled along with eMOLT collection.

Project	***Region***	***Biological Focus***	***Years***	***Mth***	***#drifters***	***Drogue depths(m)***
Mass Bays	Mass Bay	Nutrients	1990-1	2-10	6	6
ECOHAB	Mid-coast	Alexandrium	2001	5,6	6	1
MERHAB	Mid-coast	Alexandrium	2003-4	5,6	19	1,13
eMOLT	GoM	Lobster	2004	5-9	16	1
WHCOHH	GoM & BoF	Alexandrium	2005-6	5	24	1,13
NEC	Mid-Coast	Lobster	2005	7,8	16	5
NOAA	G. S. Channel	Calanus/Whales	2005-6	4,5	12	1
TOTAL				4-9	100	1,5,6,13

ECOHAB= Ecosystem Monitoring of Harmful Algal Blooms
MERHAB=Marine Ecosystems Response to Harmful Algal Blooms
eMOLT= Environmental Monitors on Lobster Traps
WHCOHH= Woods Hole Center of Oceans and Human Health
NEC= Northeast Consortium
NOAA= National Oceanic and Atmospheric Administration

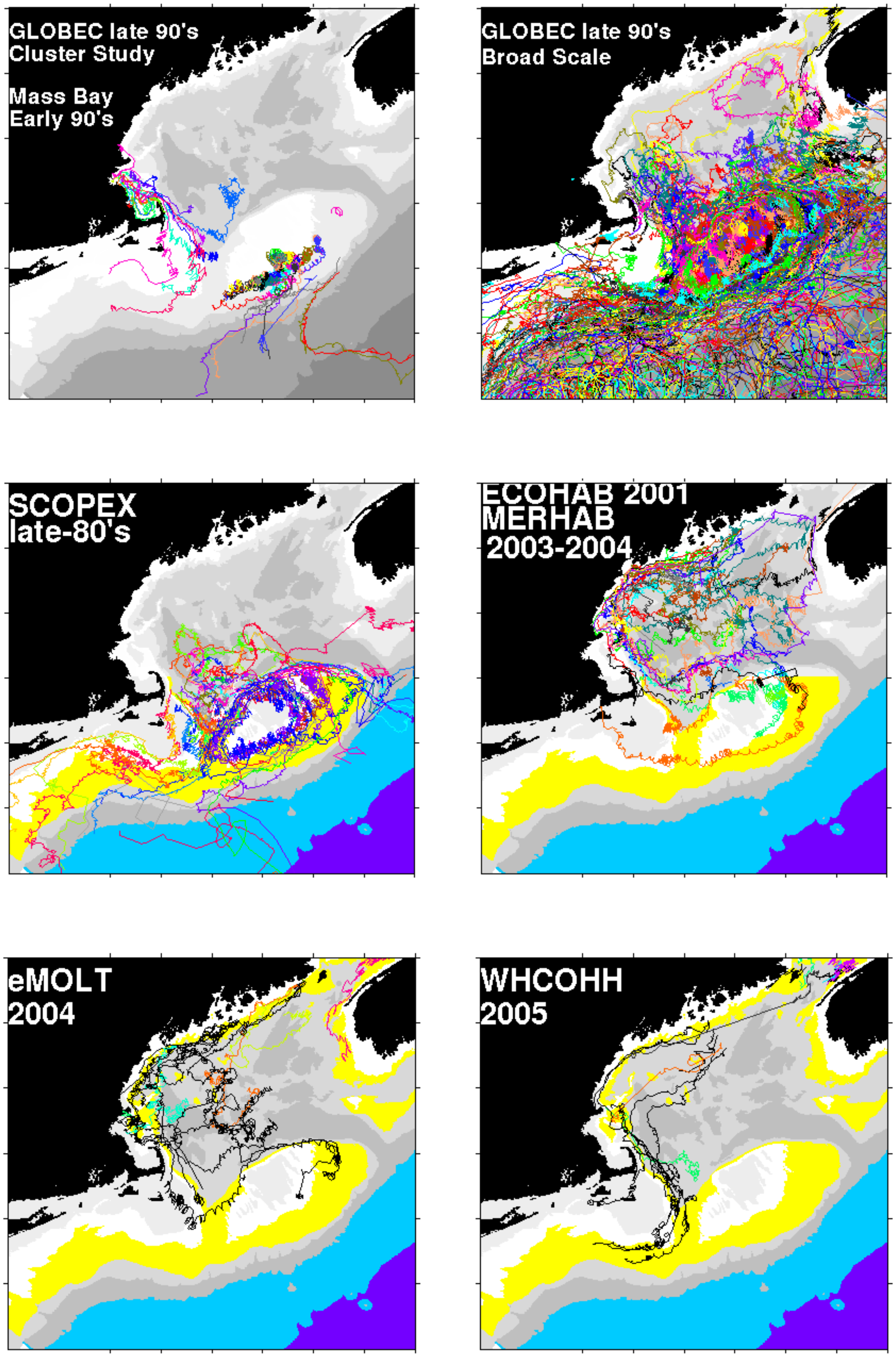


Figure 10. Historical archive of drifter tracks in the Western Gulf of Maine (missing RMRP set).

Results and conclusions

Electronic-less units

Very little can be concluded from the electronic-less drifter results. While travel times and distances document significant displacements from launch locations (Figure 11), the paths taken to arrive at the final locations are obviously uncertain. Except for a few cases where these drifters were sighted multiple times, only end points are available. Given the deliberately-low profile of these units on the water, they were evidently difficult to

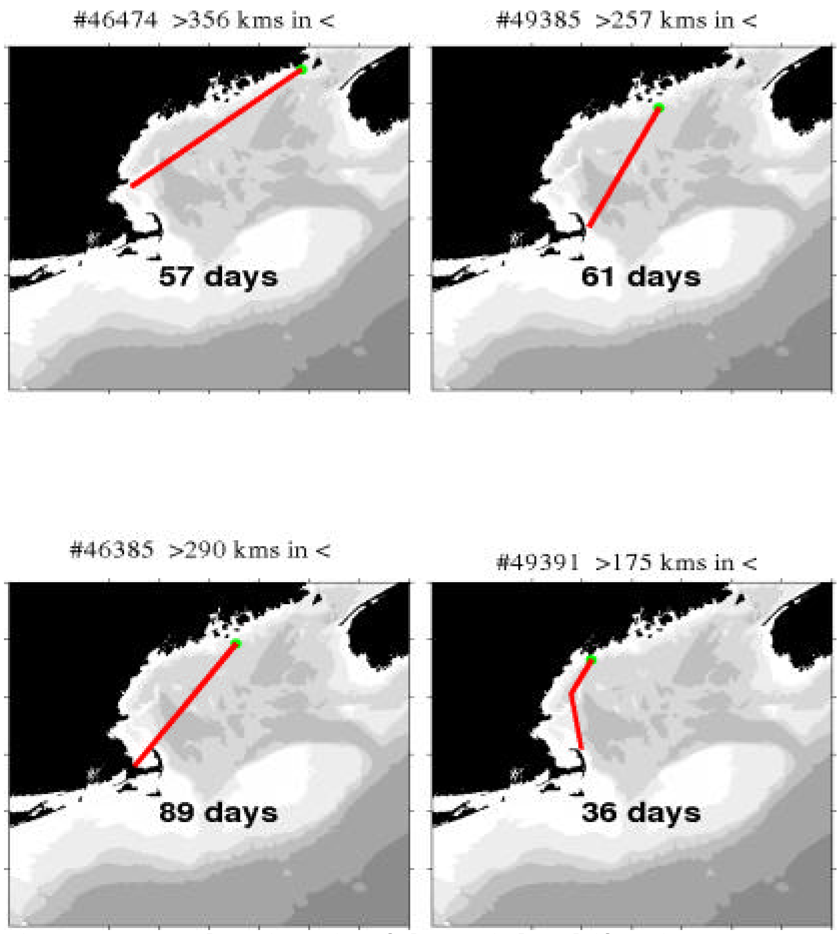


Figure 11. Example trajectories of electronic-less drifters in 2004.

distinguish from standard lobster gear through the excessive fog in the summer of 2004, especially. Nevertheless, the results should not be lost from the historical collection. The remainder of the result section, however, refers to the electronic units with GPS fixes.

Individual drifter tracks

Each drifter track is interesting in itself and as such is presented in separate panels in

Figures 12 through 15. The Cutler deployments (Figure 12) portray the significant speed of the Eastern Maine coastal current. The majority were advected away from the coast with the August release being the exception.

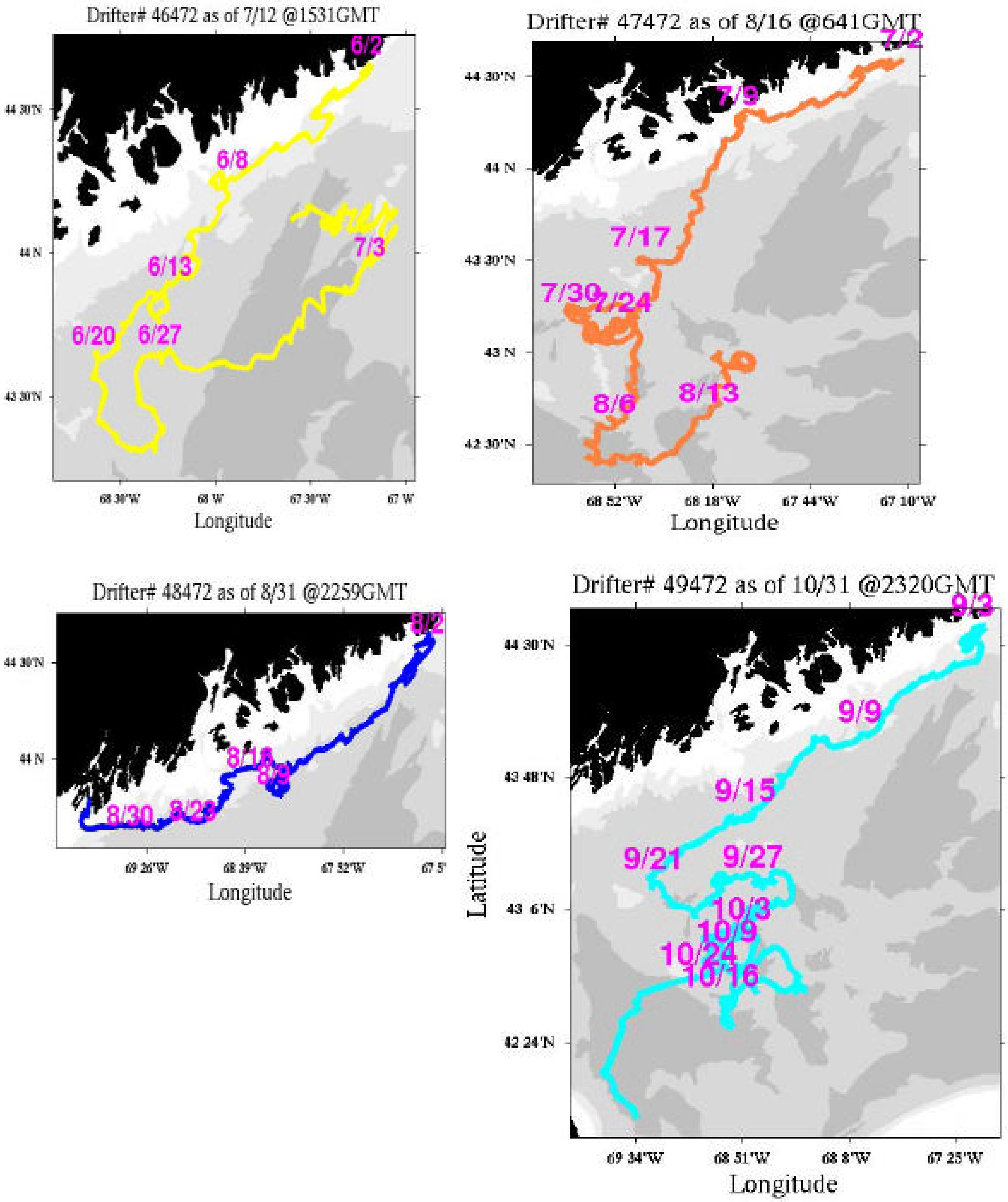


Figure 12 Drifters deployed from Cutler in Jun, Jul, Aug, and Sep 2004.

The Isle au Haut deployments (Figure 13) document a variability of fate. The June unit ended up ashore on the New Hampshire coast, the July unit was ejected from the jet on the Northern flank of Georges Bank a little more than 2 months later, the August unit headed straight south towards Georges Bank, and the September unit made it to the outer Cape Cod waters in little over a month.

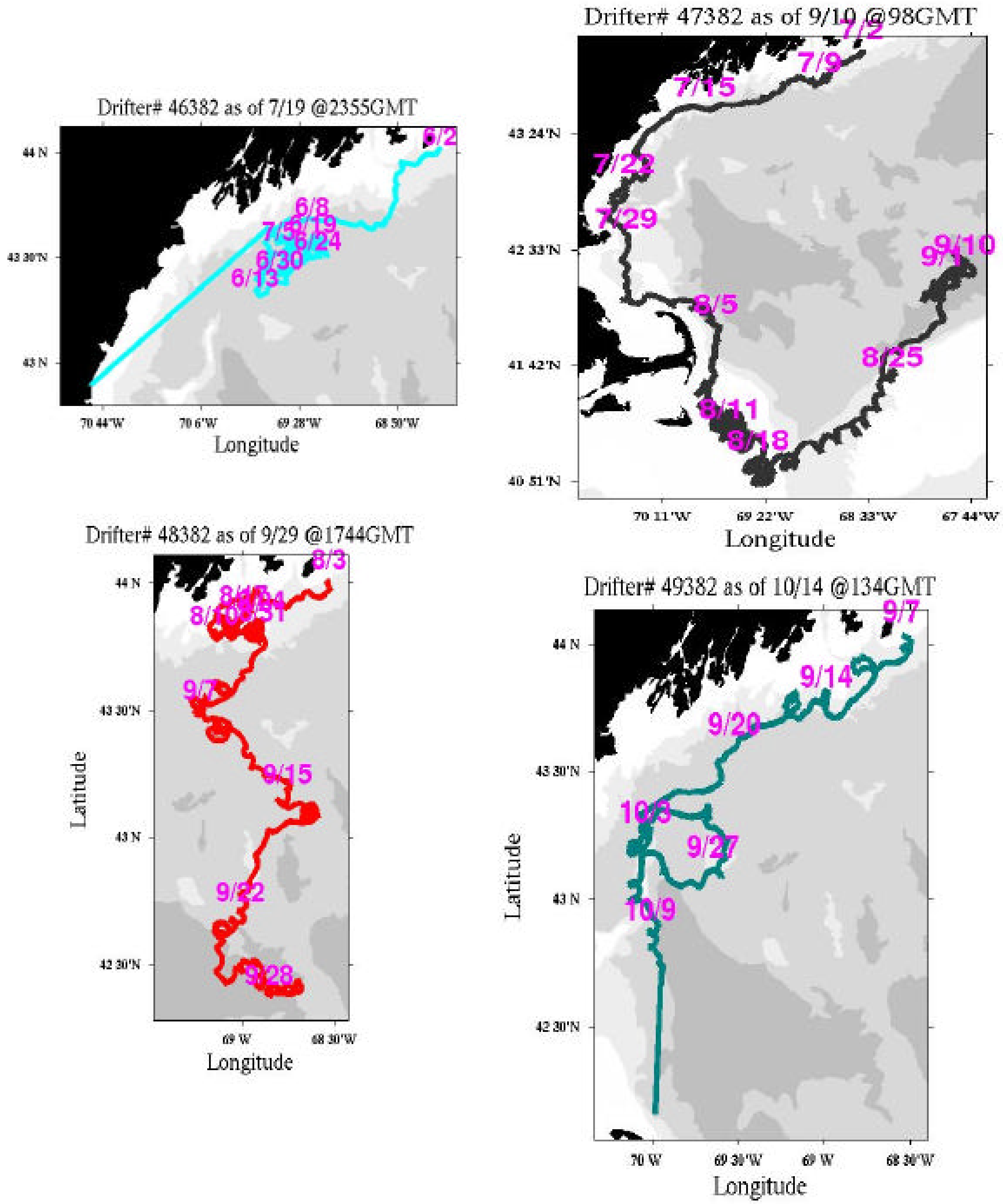


Figure 13. Drifters deployed off Isle au Haut in Jun, Jul, Aug, and Sep 2004.

The Cape Small drifters (Figure 14) ended up on Georges Bank (June), nearby Harpswell Sound (July), Mass Bay (August), and Nantucket Shoals (September).

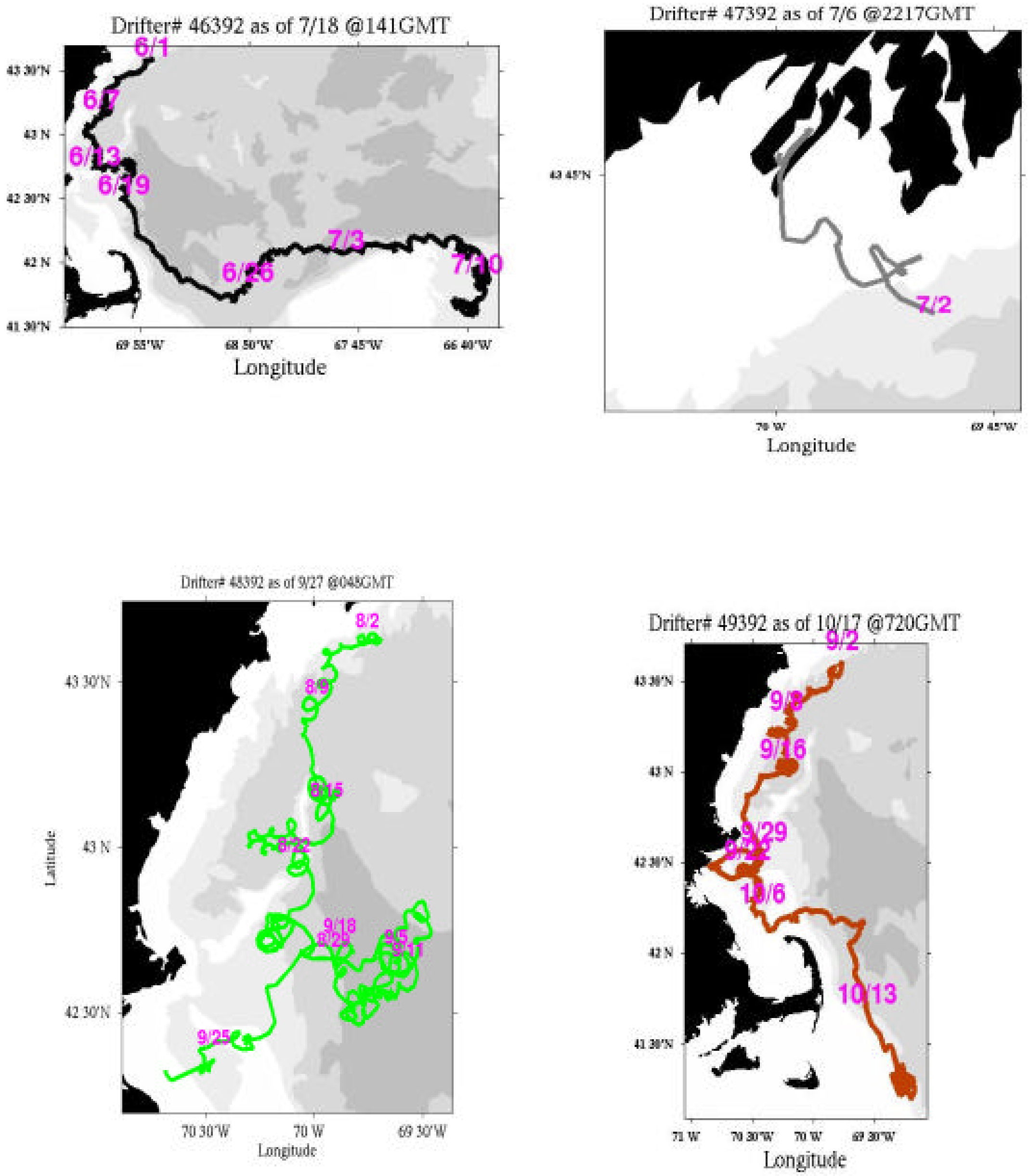


Figure 14. Drifters deployed off Cape Small (NE of Casco Bay) in Jun, Jul, Aug, and Sep 2004.

The Gloucester drifters (Figure 15) were the most variable in terms of trajectories. The prototype GPS drifter deployed in March 2004 first headed northeast and then turned around to finally wash up at the MWRA sewage treatment plant outside Boston about a week later. The GPS unit deployed in June washed ashore within a day but subsequent deployments ended up in Truro, Ma. (July) and on Georges Bank (August). The unit deployed in September only lasted a few days.

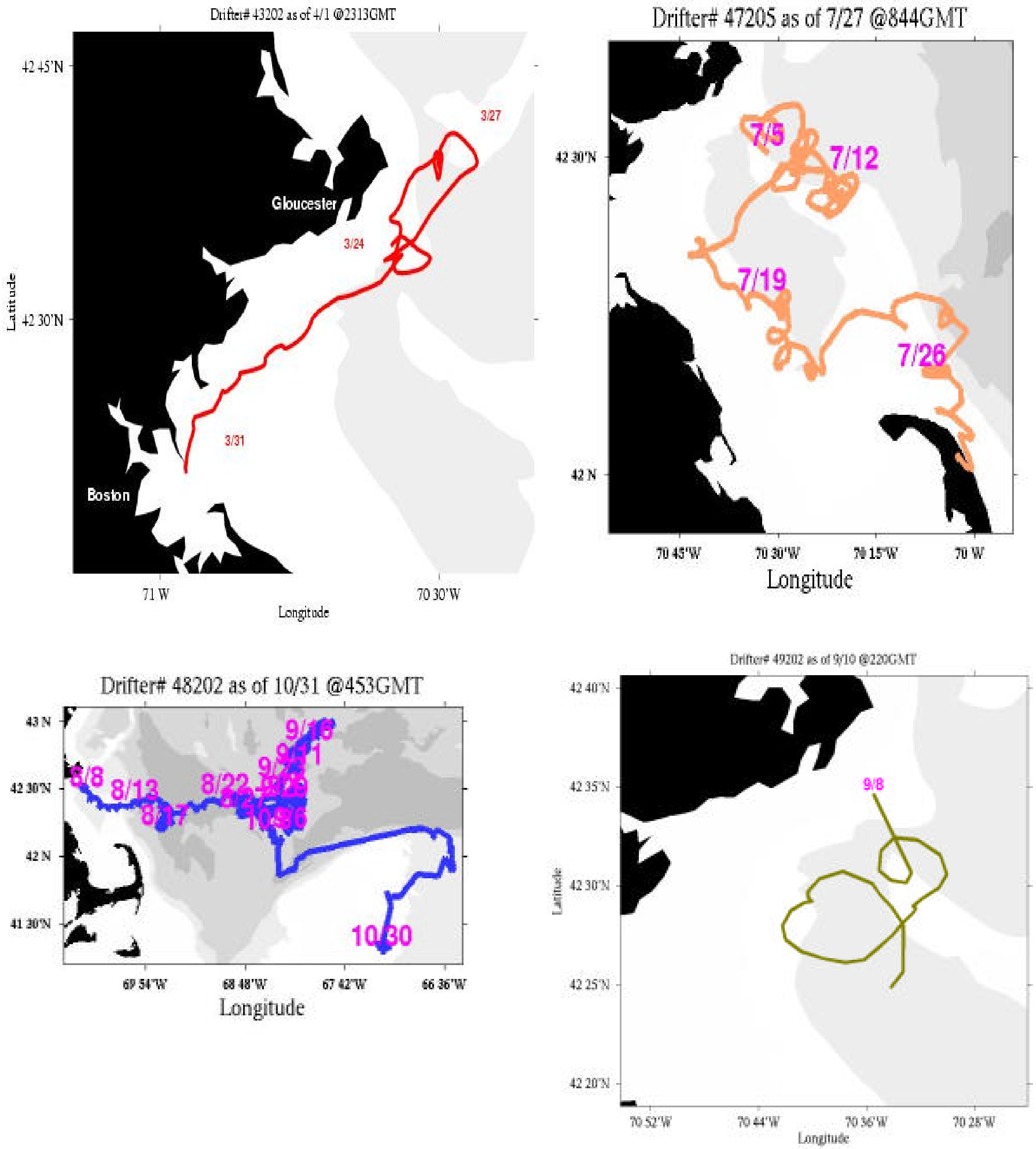


Figure 15. Drifters deployed off Gloucester in Mar, Jul, Aug, and Sep 2004.

Flow Statistics

In addition to these individual deployments noted above, there are several other tracks in most regions now archived in the database that can be used in a statistical analysis of the flow field. Flow statistics for each of the five regions (Table 3) indicate a deceleration of surface flow from downeast towards Mass Bay. The mean residual velocities downstream of Cutler typically run near 13 cm/sec and decrease to less than 10 cm/sec in the WMCC (Figure 16). The four Cutler drifters, deployed one per month Jun-Sep 2004, recorded the strongest flows (relative to others deployed further south that summer) with typical transit times to the Isle au Haut region of little more than a week (9 day mean). Of the four deployed in the same location, only one took the inside shore route eventually washing ashore just northeast of Casco Bay.

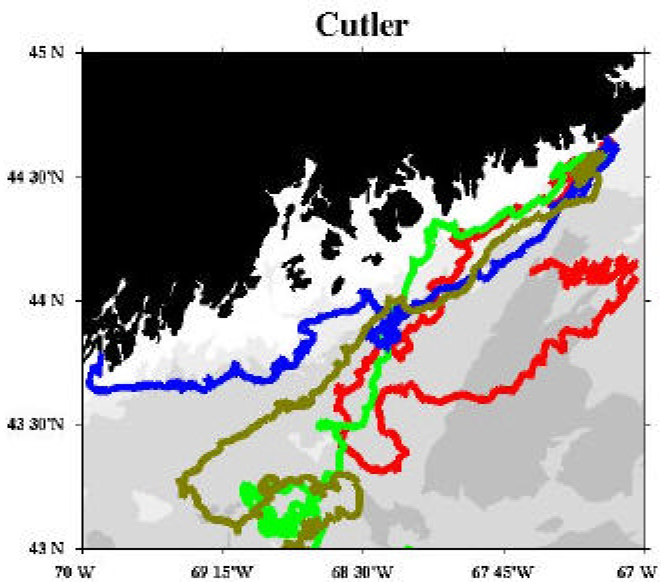


Figure 16. Tracks beginning in Cutler Maine.

The units deployed off Isle au Haut in waters less than 100m (and those intersecting that transect from the northeast) are shown in Figure 17. Here we see the generally along-isobath flow with approximately 20% flowing inside the island of Matinicus and only a few making the trip inside of Monhegan. The box statistics were calculated for a larger box extending offshore. Figure 18 demonstrates the frequent excursions of units into the central gulf as opposed to those pictured in the detailed inshore units of Figure 17. In the mid-coast region where the data coverage is significantly more than other regions, a calculation of percent loss to both the inshore and offshore sides of the coastal current (Figure 19) shows that very little (~5%)

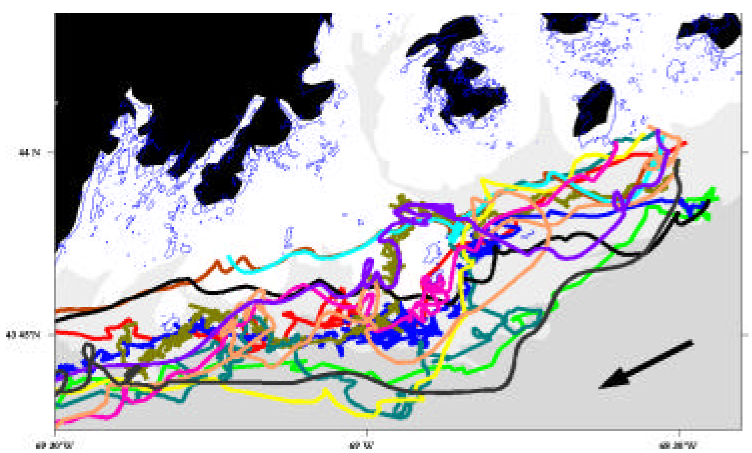
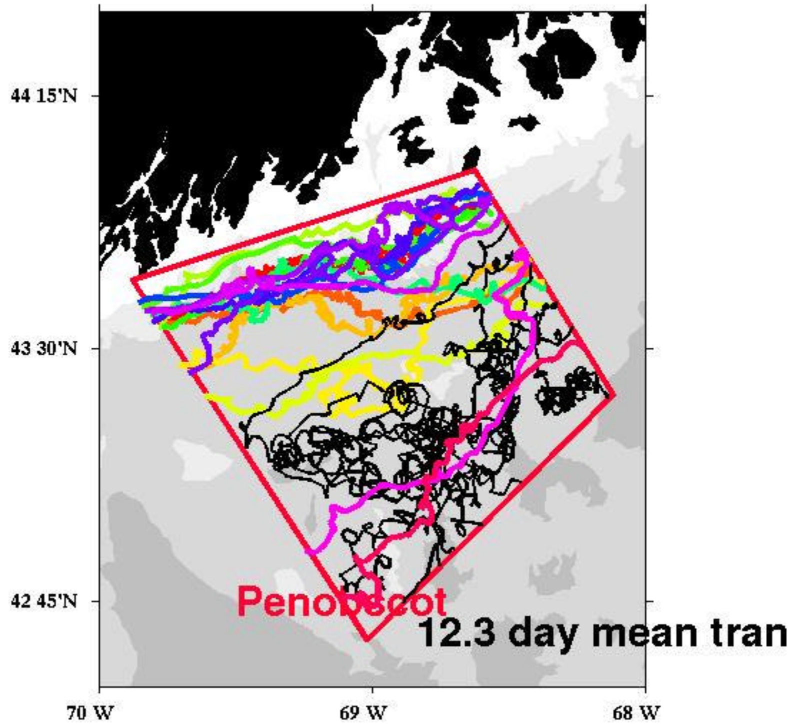


Figure 17. Tracks emanating from Isle au Haut inshore waters.



gets into the inshore region while a large percentage (~30) is ejected offshore. The black lines in Figure 18 indicate those units that exited the box on the offshore side and were not included in the 12.3 day mean transit time.

Figure 18. Tracks eminating from Isle au Haut including offshore units.

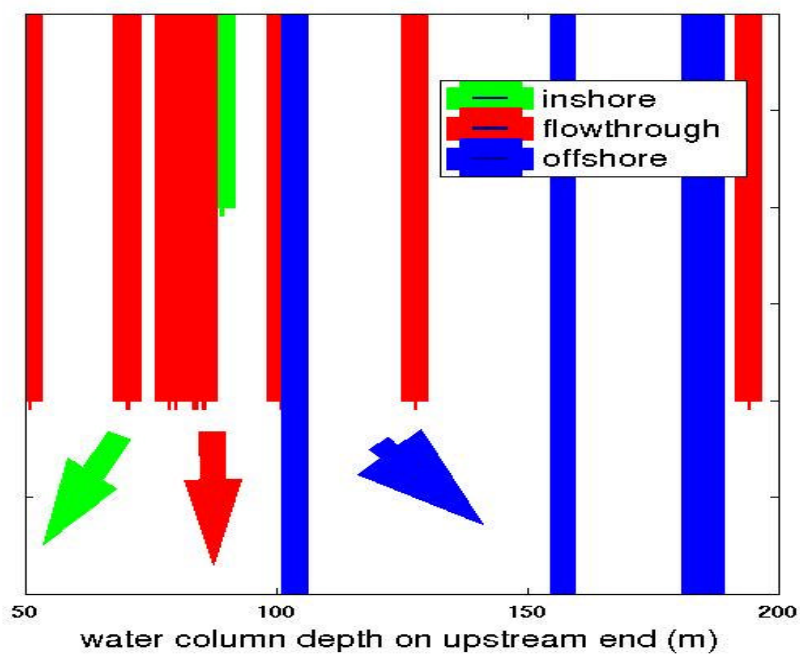


Figure 19. Fate of particles relative to water column depth on entering Isle au Haut box showing those in >100m often advect offshore (blue).

Table 3. Flow statistics per region

	#drifters	Eastward	Northward	Transit	Max eastward	Max Northward
		cm/s	cm/s	days	cm/s	cm/s
Cutler	11	-9.43	-7.24	9	64	-81
Isle Au Haut	43	-9.12	-2.91	12	51	-118
Cape Small	35	-8.19	-7.14	12	46	-99
Stellwagen	31	8.48	-9.82	5	81	-77
Truro	8	6.4	-18.96	5	38	-66

The variability of flow increases in the downstream direction in that speeds off southern Maine are less persistent and often include periodic excursions away from the coastal current core. On many occasions drifters in this WMCC region (Figure 20) were ejected from the primary current and meandered about before being reentrained into the southwestward flow. This appears to happen in the case of the purple and blue lines in Figure 20, for example. Those closer to shore have a more direct and persistent flow SW of Casco Bay. Again, only a small percentage of the units entering from the NE of Casco Bay were advected towards shore and into Bay.

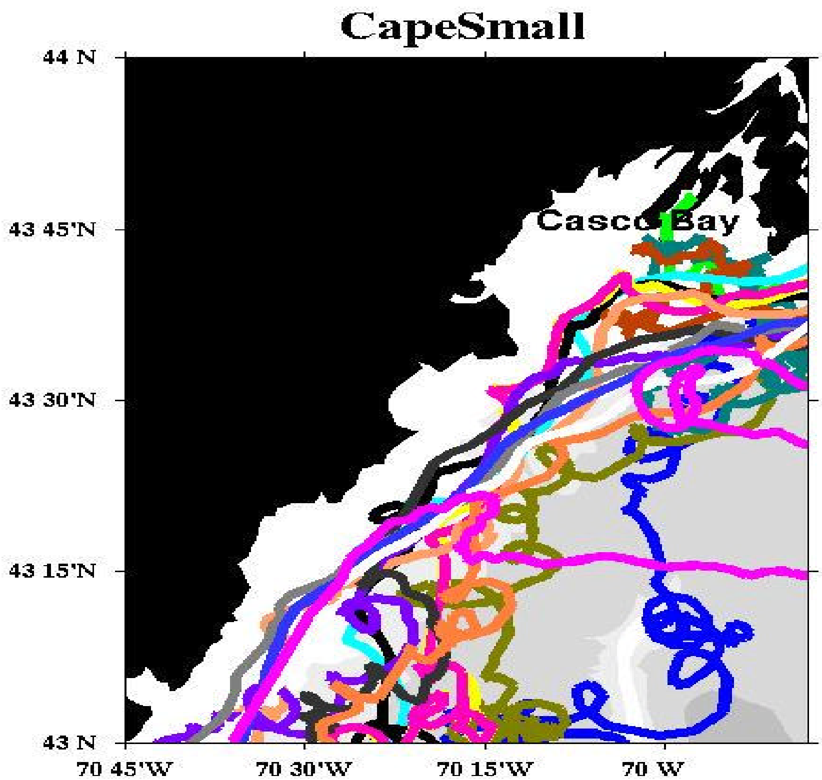
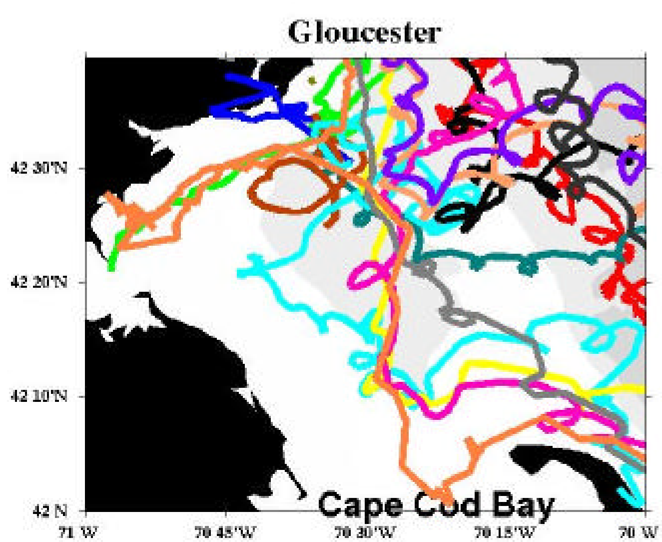


Figure 20 Tracks beginning at Cape Small longitude.



In some regions, there appears to be zones of static flow where drifters appear trapped in localized areas. One such case is in the vicinity of Jeffrey's ledge and the Isle of Shoals, for example, where on a number of cases drifters were held up for days before proceeded further towards Mass Bay. As noted later in the analysis of events, the Nantucket Shoals and a particular site in the Bay of Fundy also appears to be an area of retention despite both being a very tidally dominated region.

Figure 21. Tracks entering from Gloucester latitude.

Continuing further down the coast into the area of Mass Bay, Figure 21 illustrates the complex pathways associated with this region. Again, of all the units entering the northern border of the box, only a few are advected ashore, only one makes it into Cape Cod Bay, with the majority moving offshore, as illustrated in Figure 22, towards the Great South Channel.

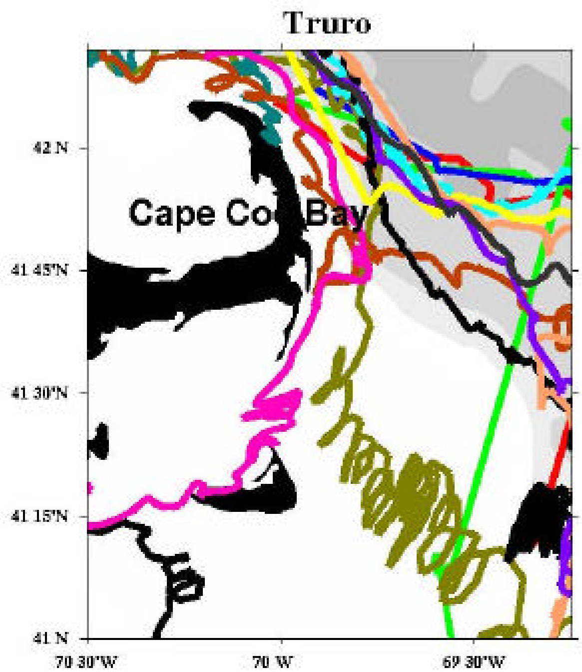


Figure 22. Tracks coming around Race Point.

Here again, one drifter comes ashore on the oceanside of Truro, one enters the Nantucket Sound, but the majority continue along-isobath towards the GSC. The dark green olive and the black lines document cases where drifters were retained for several days in an area nearly as small as the tidal ellipse. The straight light green line represents the travels of a drifter over the period of less than two days during a northeaster in early May 2005, where rather than continue on the more normal track to Georges Bank, it was quickly affected onto the Nantucket Shoals and into the Middle Atlantic Bight. More examples of these short wind-driven effects are examined later in the discussion.

Finally, there are several cases where four or more drifters were deployed at the same location (within a tidal excursion distance of a nominal position) and at different times. While the "Cutler" releases (Figure 16 where the drifters were deployed once per month during the summer of 2004 eMOLT project) is one example, there are several other cases as illustrated in Figure 23 below that demonstrate the variability of fate despite having nearly the same deployment location. The four drifters released at a particular site that same summer off Isle of Haut, for example, traveled very different paths. Those deployed at the Mass Bay outfall site in the summer of 2005 (top right panel) also resulted in different paths but, in this case, the depth of the drogues vary slightly between deployments. In the case of Cape Small, one can see the extreme difference of the green vs blue line being taking inshore and offshore routes, respectively. The most confused of

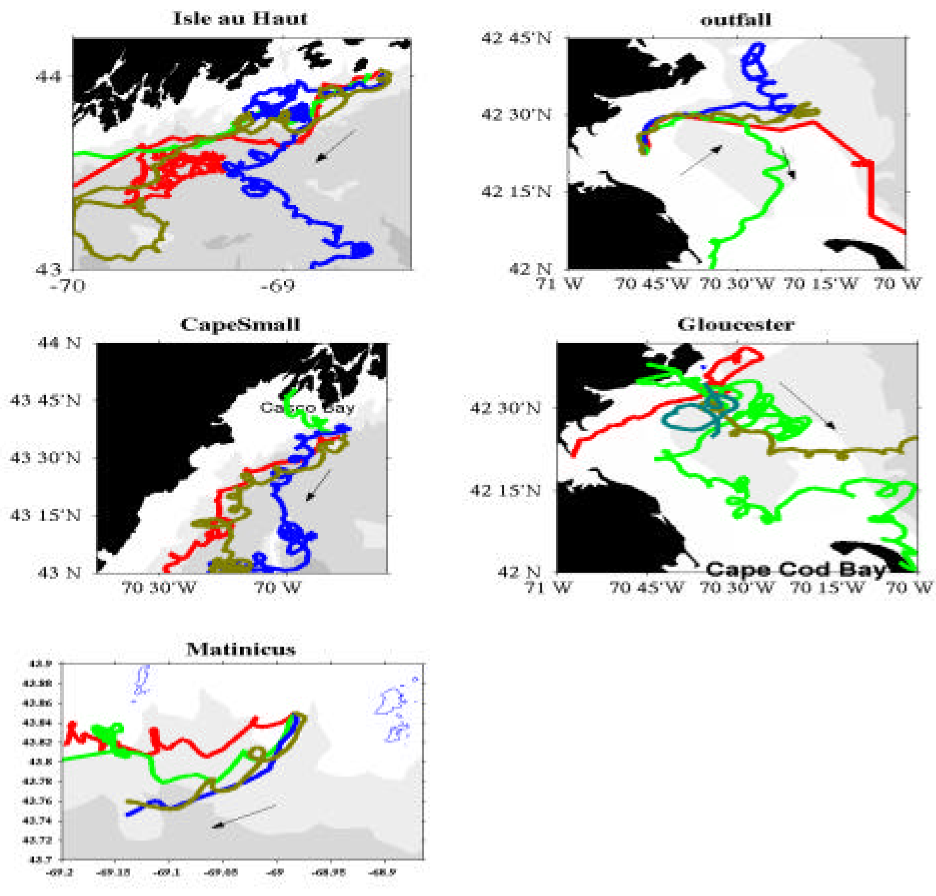


Figure 23 Example of drifter tracks emanating from a single location.

all flow patterns, however, is in the case of a deployment site off Gloucester which resulted in flow in nearly every direction. Finally, the lower left panel depicts the results of a smaller scale experiments in between the islands of Matinicus and Metinic off Penobscot in mid-summer 2005 where drifters were deployed at the same spot only days apart and documented a differences in trajectory paths even over these smaller time scales.

Drogued vs surface drifters

While satellite imagery is limited in the Gulf of Maine, there are periods of clear skies on approximately a near-weekly basis. A few images were available, for example, during the extensive MERHAB deployment in late May 2004 which provided a synoptic picture of the coastal current and its complicated structure off the mid-coast region (Figure 12).

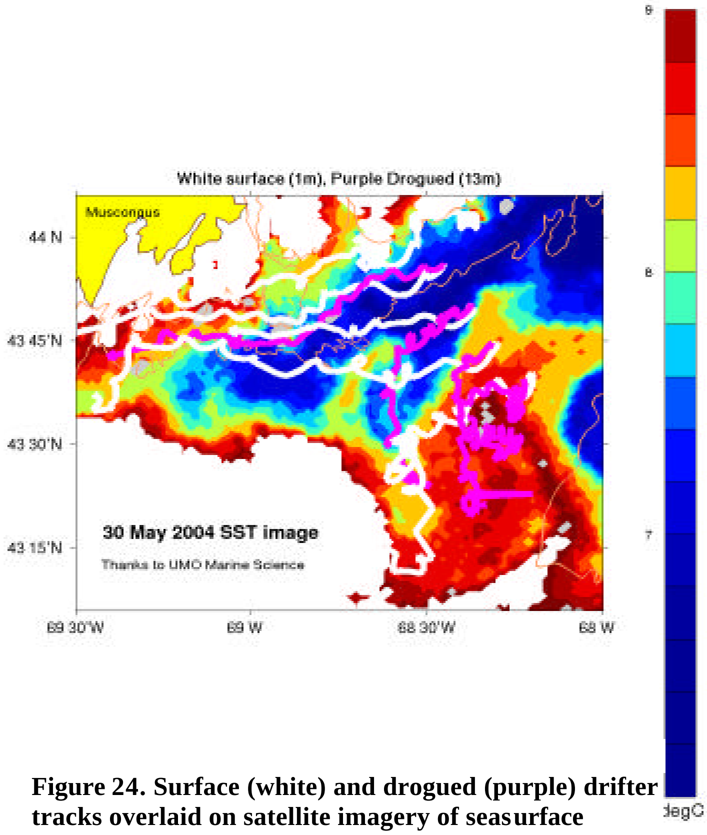


Figure 24. Surface (white) and drogued (purple) drifter tracks overlaid on satellite imagery of seasurface temperature demonstrating the depth-dependent pathways.

The drogued drifters (centered at 13m) of this deployment in a few cases were diverted offshore relative to the surface drifters deployed at the same location (within a few hundred meters).

A comparison of Eulerian and Lagrangian velocities in cases where drifters path's were deemed close enough to the mooring location shown very similar results. The slightly larger Lagrangian values are expected since they are more apt to experience the core of the coastal current whereas the mooring locations are fixed..

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Xue, ,H., F.Chai, and N.Pettigrew, . 2000. A Model study of the seasonal circulation in the Gulf of Maine, J.Phys.Oceanogr. In Press

Partnerships

The eMOLT drifter project was truly a collaborative effort. In addition to the administrators listed in the “participants” section above, there was also the lobstermen who actually conducted most of the field work (Appendix I), the marine science students who actually built the drifters (Appendix II), and the mariners who sighted and reported drifter fixes (Appendix III). All of these individuals contributed to the end result. The lobstermen, for example, provided feedback to the science party on the feasibility of deployment sites. Having first hand knowledge of the waters and the local bathymetry of their respective deployment sites, they could help in deciding where to locate the dropsites. As noted below, the students were involved with every aspect of drifter production and contributed several suggestions in the design and fabrication of the drifters. Finally, hundreds of people in the New England maritime community were notified about the project in many public forums and in the press. A total of 52 individuals responded by reporting drifter sightings. A list of these people and addresses (where available) is archived in Appendix III. An eMOLT baseball cap and a short description of the project results was mailed to these individuals in early 2005 as a token of our appreciation.

Impacts and applications

As noted in final reports of earlier phases of eMOLT, one could say that NOAA is the primary "end-user" of the eMOLT project. As NOAA and Ocean.US prepare for the implementation of a nation-wide ocean observing system (OOS), they will begin with an integration of existing observational networks. What better place to begin than with the individuals who already spend their days at sea, have the biggest stake in preserving the resource, and are the most knowledgeable of the local waters? If NOAA intends to invest in the future of our coast, these individuals need to be recognized, recruited, and supported for their efforts. NOAA needs to look towards the many organizations of fishermen such as local lobstermen associations. GoMOOS, a prime example of a regional OOS, has done well in this respect by catering to the industry's need. They have been present at many of the forums where fishermen congregate, have listened to their needs, and have recognized eMOLT as a means to supplement the data they collect.

Related Projects

Clearly the projects that are most closely related to the eMOLT drifter phase are those investigating the transport of *Alexandrium fundyense* along the Western Gulf of Maine. Here, the scientific question is nearly the same as the lobster larvae investigation: How does a particle come up from the bottom and, having risen to the near-surface layer, get advected along and into the coastal region? A series of projects including ECOHAB, MERHAB, and WHCOHH addressed this process in the past decade. After the devastating harmful algal bloom event in May of 2005, investigators are predicting more events in the next few years and have proposed millions of dollars to research further. The drifters developed with eMOLT funding are an integral part of these proposals.

One approach to this type of HAB study is to deploy drifters in offshore patches of *Alexandrium* in a "rapid response" mode. This strategy was implemented on multiple occasions in the summer of 2005, for example, when eMOLT drifters were deployed by the Massachusetts Water Resource Authority at the Boston Sewage Outfall Site.

Another project that is clearly related to all phases of eMOLT is the Gulf of Maine Ocean Observing System. One of the newer aspects of their project in recent years is the development of the CODAR system for measuring surface currents offshore. One way to supplement and validate such a system is in deployment of surface drifters. EMOLT drifters have been used to help validate GoMOOS model simulations in the Gulf of Maine (Huijie Xue, personal communication).

On some occasions in the past few years, we have had close communication with our Canadian partners, the Fishermen and Scientist Research Society. Having shown some interest in the eMOLT drifter study, they agreed to deploy one of our drifters on their side of the gulf. We consequently mailed a complete drifter to them in July 2004 and a lobsterman, Aston Spinney, then subsequently deployed the unit off the southeast coast of Nova Scotia. The track of that drifter (Figure 17) documented an interesting case of rapid week-long advection up into the Bay of Fundy followed by a prolonged month-long period of retention in the tidally-dominated waters just to the east of Digby Neck after which a curious fishermen recovered the unit and brought it home.

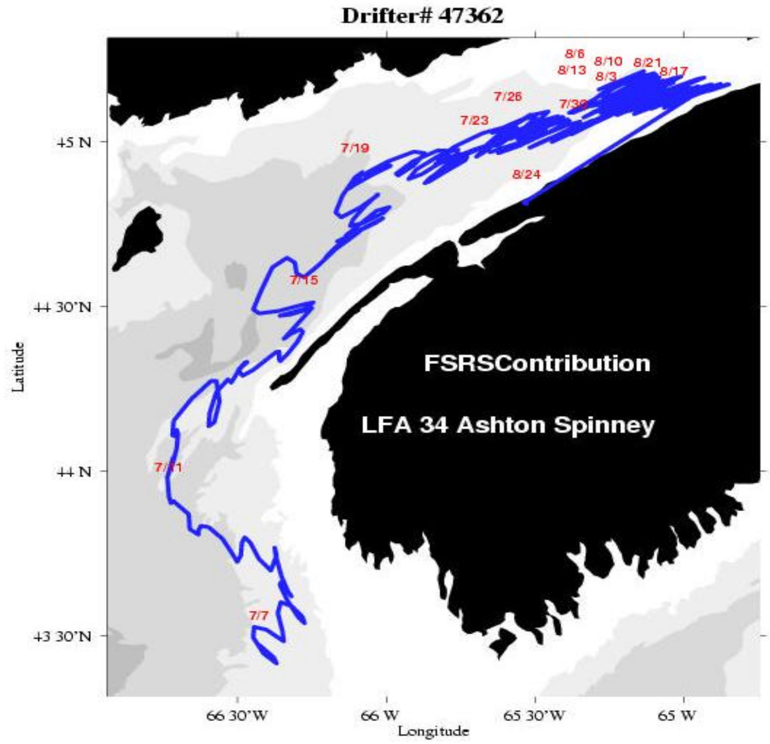

Figure 25. Track of drifter deployed by Ashton Spinney, a Canadian lobstermen, in early July 2004 demonstrating both the rapid advection outside the Bay of Fundy and retention after entering.

Presentations

The "training sessions and meetings" page of the emolt.org site lists the dozens of seminars and meetings that have been conducted over the years where eMOLT data has been presented. The most well attended of these meetings by a large variety of people with multiple backgrounds is the Mass Lobstermen's Annual Weekend and the Maine Fishermen's Forum.

The scientific aspects of the eMOLT drifter project have been presented on multiple occasions to in-house personnel at the Northeast Fisheries Science Center, the Woods Hole Oceanographic Institution, and participants of the semi-annual workshops of the New England Numerical Ocean Modelers as documented at: (http://sole.wh.whoi.edu/~jmanning/circ/nenocm.html).

Students participations

More than a dozen students have been involved with the engineering and production of drifters. A few of the students became so involved with the project they have subsequently taken summer internships (both 2003 and 2004) with the Gulf of Maine Lobster Foundation. Two of them went on to university level studies in the physical sciences. We expect many more marine science students to be involved with these drifters in the years to come. The full list of faculty & students involved is listed in Appendix II.

The students are also involved with the handling of drifter data. Tom Long, who teaches the Geographic Information System course at SMCC, and his students have downloaded the eMOLT drifter data (freely available on the web) and is incorporating it into his curriculum.

Finally, the fifth grade class at Truro (Ma) Elementary School, under the direction of their teacher Mr. John Burns, did a semester-long project on the eMOLT project. After Mr. Burns found a drifter washed up on the oceanside of Cape Cod in the late Fall 2004, he brought it into the classroom where the students accessed the website (as instructed on the drifter's sails) and conducted research on the project. Each group of students studied various aspects of the project including the life history of lobsters, the circulation patterns of the Gulf of Maine, and the story of Stonington, Maine, the home port of Stevie Robbins III who had deployed the drifter months before. After a full page article in the Cape Cod Times related the story, Jim Manning subsequently visited the students to make a presentation in the classroom. He was impressed at the degree of investigation that was conducted by the students who had prepared their own Power Point presentations and questions concerning the project.

Published reports and papers

A condensed version of this report "Manning, J.P., D.J. McGillicuddy, W.R. Geyer, J.H. Churchill, and L. Incze, 2006, Observations of Maine Coastal Current Drift." is in preparation for a journal submission. At the time of this writing, the manuscript looks at the statistics presented in preliminary form within this document. The investigation incorporates the historical archive of drifter data from the Gulf of Maine and summarizes the observed flow characteristics in each sub area. Otherwise, the publication of eMOLT data in this project and in all phases of the eMOLT project has been distributed on the web. The eMOLT project has been written up in the press many times as documented at the "eMOLT in the News" site linked from the homepage emolt.org.

Images

In addition to the images imbedded throughout this document, there are hundreds of illustrations on the emolt.org website. Under the "eMOLT Photos" page, for example, there are dozens of digital photographs of the "drifter evolution" to document its development from 2003 through present. One of the most powerful presentation of the project results are posted in the form of animations. These are linked from multiple places on the eMOLT "drifter study" page.

Future research

Having successfully developed both a drifter technology and a network of mariners to deploy and recover these instruments, there are now opportunities to conduct a variety of research on particle drift in the Gulf of Maine. The hope is to now turn more attention to the numerical simulation of the processes that have been observed. From the very beginning of eMOLT development, the primary objective in collecting a broad range of data is to help initialize, assimilate, and validate various coastal ocean models in the region. This type of activity has already been underway at both the University of Maine Orono, the University of Mass at both Dartmouth and Boston, the University of New Hampshire, and the Woods Hole Oceanographic Institute where modelers have used eMOLT drifter data to examine model performance (He et al., 2004).

Appendix I. Lobstermen who deployed drifters

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Appendix II: List of SMCC faculty & students involved with eMOLT drifter production.

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Appendix III. **Name and addresses of the general public who reported drifter sightings in 2003 and 2004 including the ID# of the drifter reported.**

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